NSTX-U

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Progress and Plans for Transport and Turbulence

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and the NSTX-U Research Team

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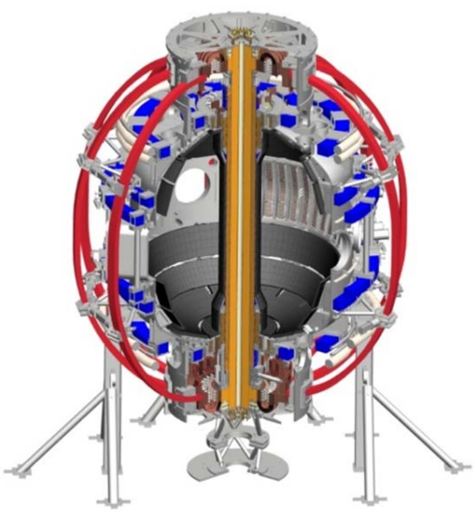

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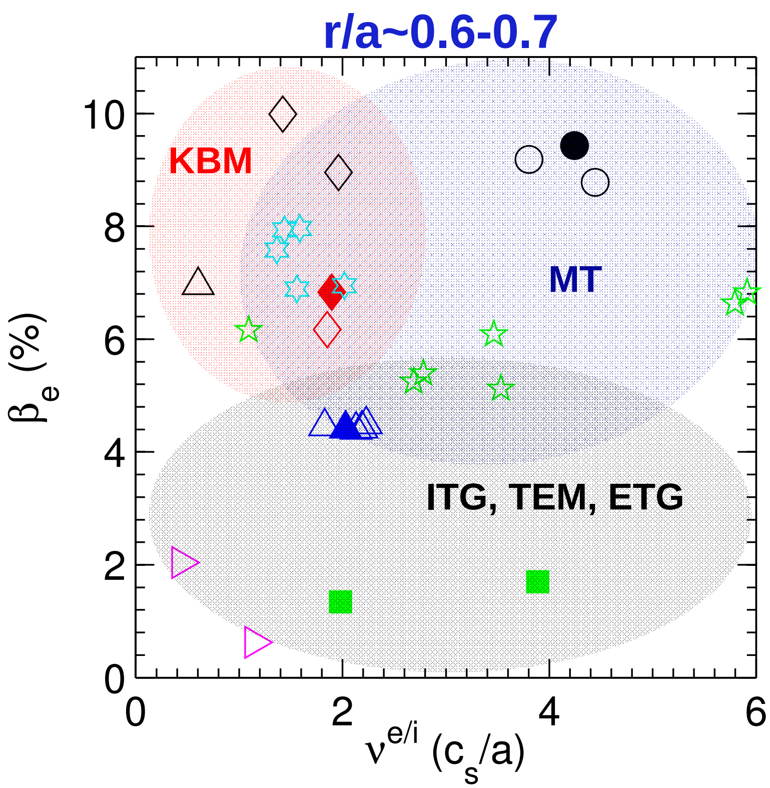
NSTX-U Transport and Turbulence (T&T) research aims to establish predictive capability for performance of FNSF & ITER

- Challenging and exciting as:
  - NSTX-U accesses a variety of drift wave transport mechanisms

All potentially relevant for ITER & other tokamaks



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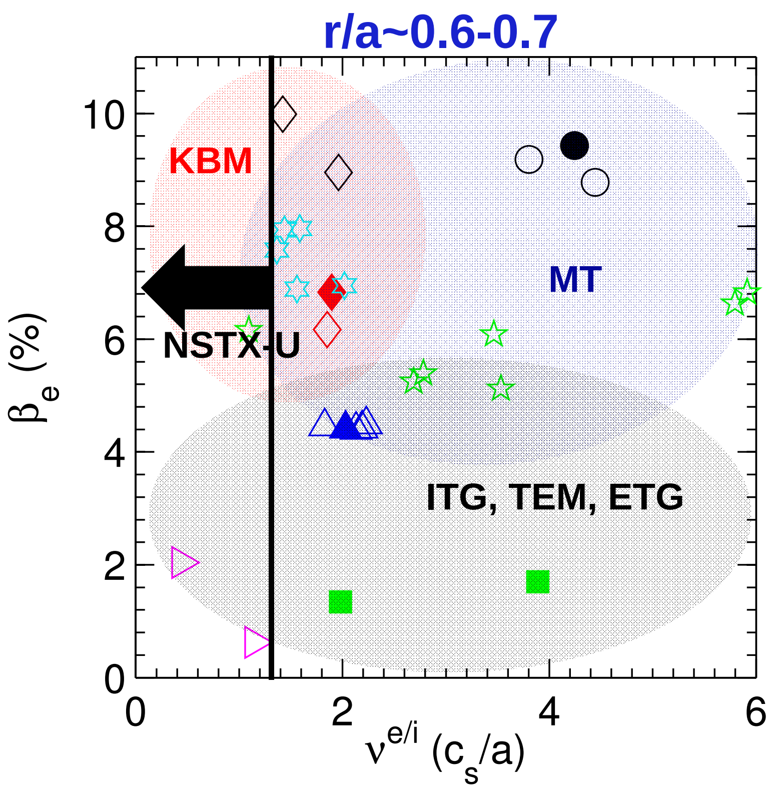
  - NSTX-U is unique in achieving high β and low collisionality regime



Will τ_E~$1/\nu_*$ remain valid?
Will microtearing be suppressed?
Will $\chi_i \approx \chi_{i,NC}$ & $D_{imp} \approx D_{imp,NC}$ hold?

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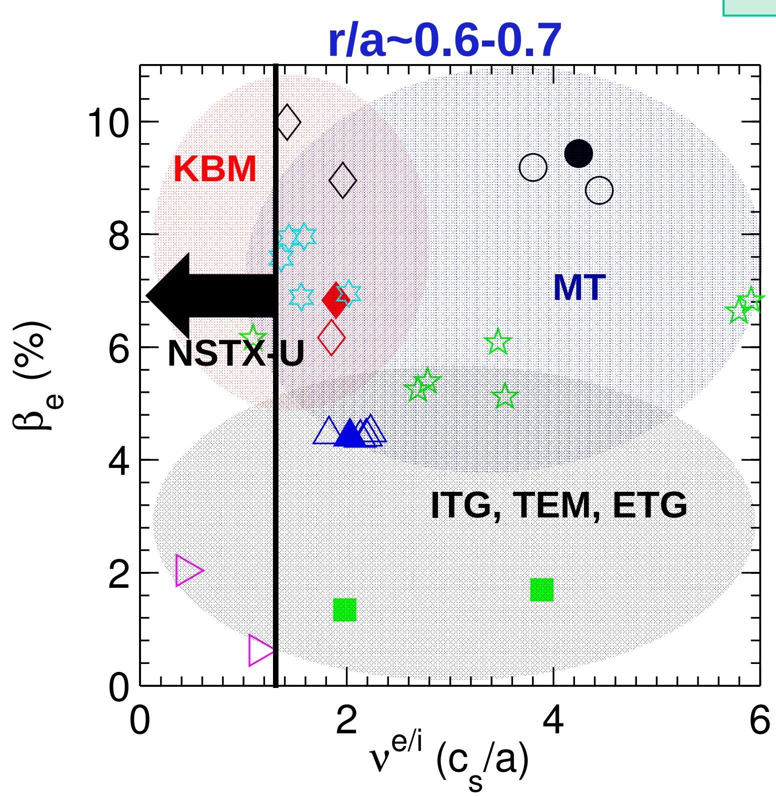
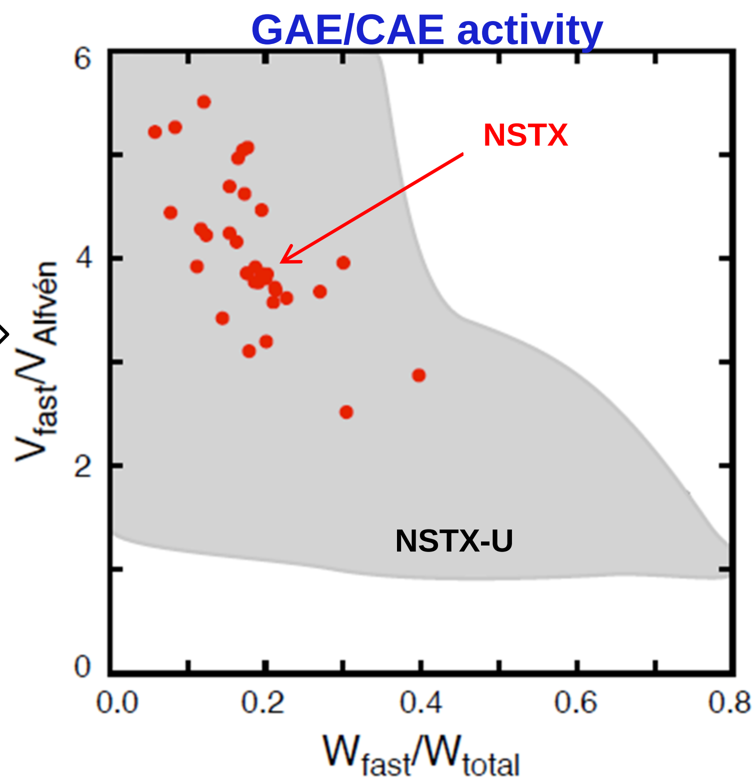
  - Electron thermal transport can also be driven by Global & Compressional Alfvén eigenmodes (GAE/CAEs)

What is role of GAE/CAE setting $T_{e,0}$?
How will GAE/CAE respond for higher field, 2^{nd} NBI?





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  - Electron thermal transport can also be driven by Global & Compressional Alfvén eigenmodes (GAE/CAEs)

- Thrust 1: Characterize H-mode global energy confinement scaling in the lower collisionality regime of NSTX-U
- Thrust 2: Identify regime of validity for instabilities responsible for anomalous electron thermal, momentum, and particle/impurity transport in NSTX-U
  - Low-k modes ($k_\perp \rho_s \leq 1$): ITG/TEM/KBM, MT
  - High-k mode: ETG
  - CAE/GAE

  } drift waves

  } Alfvén eigenmodes
- Thrust 3: Establish and validate reduced transport models

FY15-16 milestones address thrusts of T&T research

- **(R15-1)** *Assess H-mode τ_E, pedestal and SOL characteristics at high B_T, I_p, P_{NBI}*
  - Assess confinement scaling at reduced ν_*
- **(R15-2)** *Assess the effects of neutral beam injection parameters on the fast ion distribution function and neutral beam driven current profile*
  - Investigate sensitivity of GAE/CAE induced χ_e to fast ion phase space
- **(Joint Research Target 2015)** *Quantify impact of broadened current and pressure profiles on confinement and stability*
  - Study transport and turbulence response with q, s, $p_0/\langle p \rangle$ using expanded NBI flexibility
- **(IR16-1)** *Assess τ_E and local transport and turbulence at low ν_* with full confinement and diagnostic capabilities*
  - New results from high-k_θ scattering (UC-Davis), polarimeter (UCLA), enhanced BES (UW)

OUTLINE

- Recent research highlights
- Research goals and plans for FY15-16
- Summary

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- Recent research highlights
  - Turbulence measurements
  - Thermal transport, measurement and modeling
  - Momentum & impurity transport
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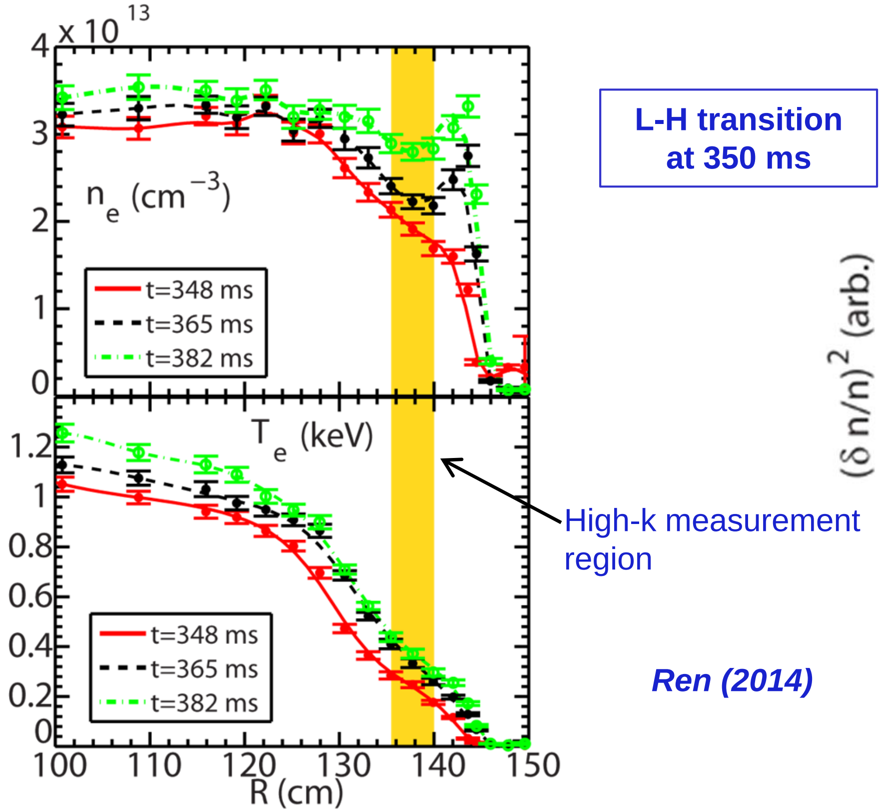
Investigating high-k turbulence and thermal transport across L-H transition early in discharge

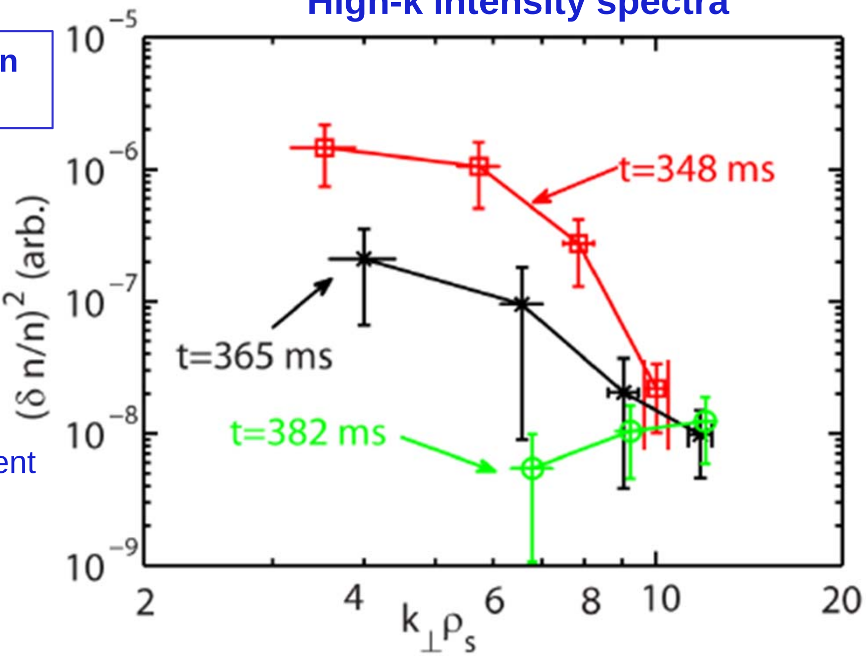
- Turbulence drop across L-H from core to pedestal (135-145 cm) seen in **high-k** (also BES & GPI), correlated with pedestal growth & confinement improvement

Thomson scattering profiles



L-H transition at 350 ms

High-k intensity spectra

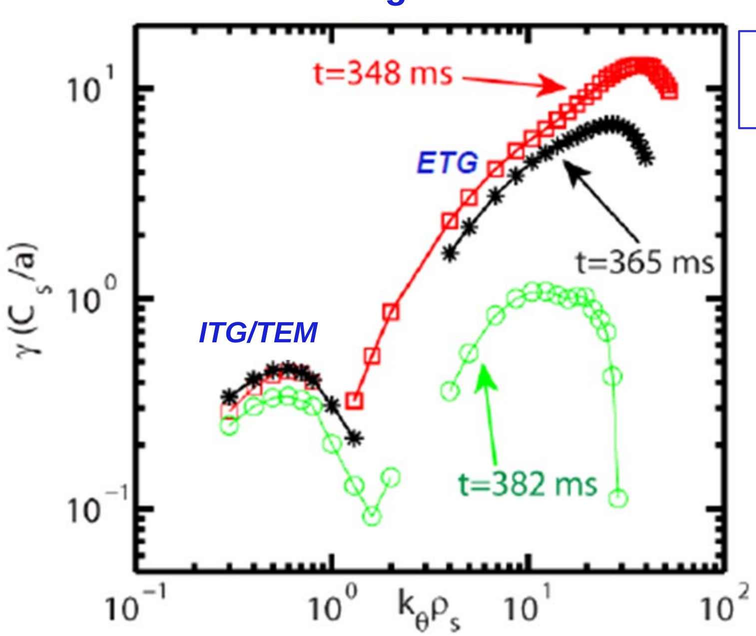


Ren (2014)

Investigating high-k turbulence and thermal transport across L-H transition early in discharge

- Turbulence drop across L-H from core to pedestal (135-145 cm) seen in **high-k** (also BES & GPI), correlated with pedestal growth & confinement improvement
- High-k reduction consistent with reduction in ETG growth rates
  - E×B shearing rate also increases in pedestal and core region

Linear growth rates



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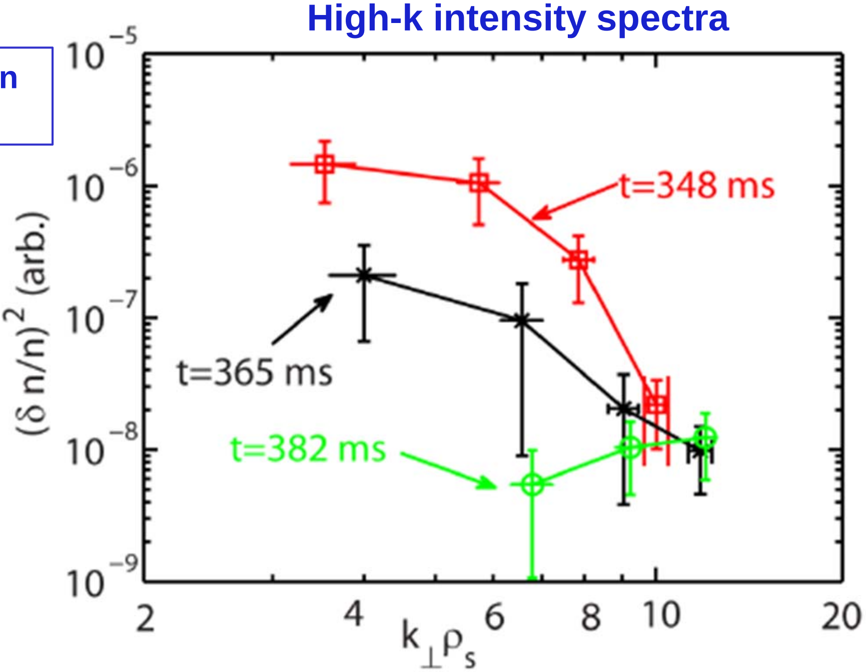


Ren (2014)

Nonlinear ITG/TEM, ETG simulations to be run in FY14-15 to determine importance of high-k

Testing reduced χ_e models for microtearing turbulence

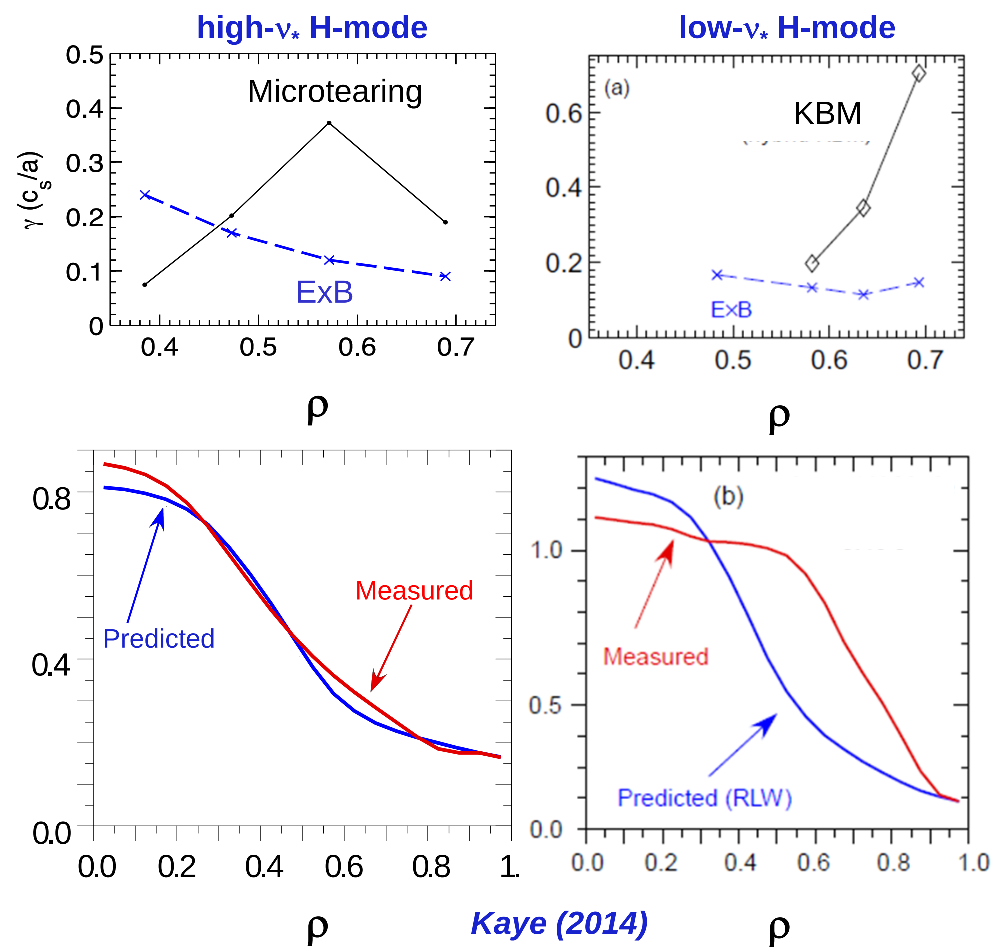
- Microtearing (MT) instability dominant in <u>high-collisionality</u> H-modes

- T_e predictions using Rebut-Lallia-Watkins (1988) microtearing model show agreement
  – Poor agreement for lower ν_* discharges

Will test physics-based TGLF transport model in FY14-15 (w/ GA, G. Staebler)

- Beginning to investigate global EM effects ($\rho_*=\rho_s/a\sim1/120$)

Collaboration with UC-Boulder, GEM (Chowdhury) EM in XGC1 (Lang, Ku) & GTS (Startsev, Wang) in FY14-15 (PPPL-Theory)



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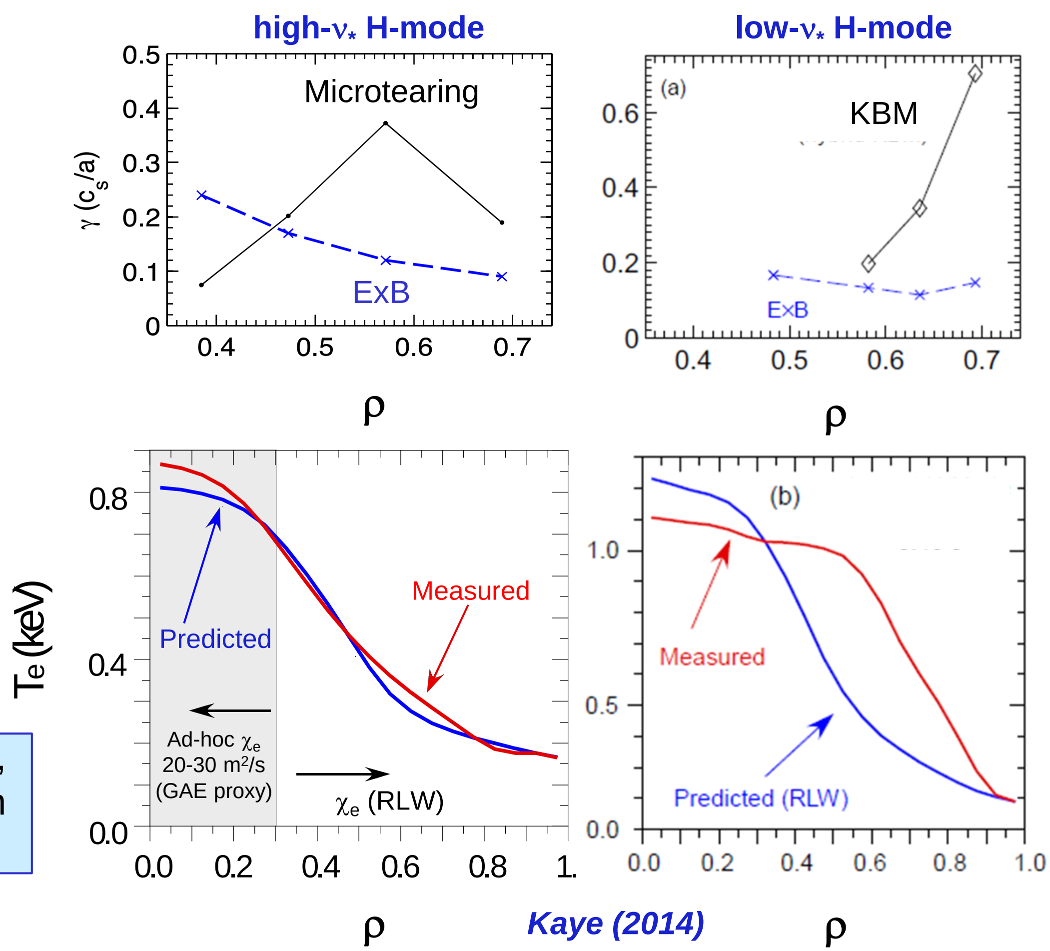


- **No drift wave instability predicted near axis – influence of GAE/CAE?**

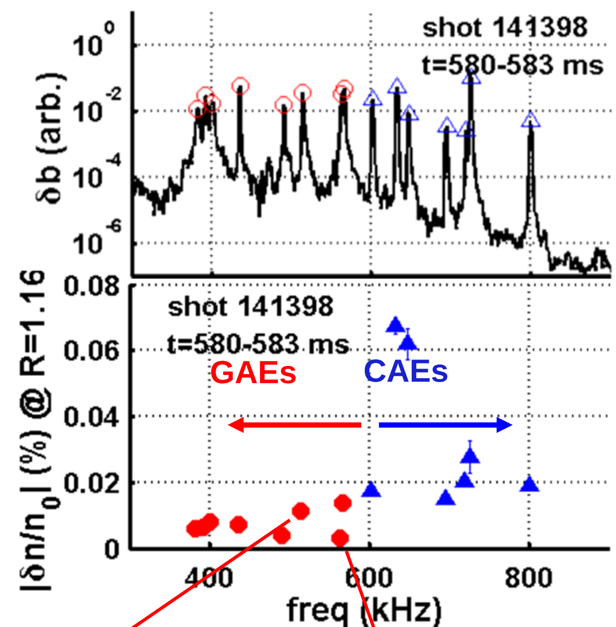
Improving model estimates of energy transport due to Alfvén eigenmodes

- Assumed GAE, CAE mode structures, amplitude, polarity used previously to model $\chi_{e,EP}$ from ORBIT modeling (Gorelenkov, 2010; Tritz, 2012)
- Measured n, ω, δn + dispersion allow distinction of GAE, CAE

Will use measured mode structures, amplitude, polarity in ORBIT simulations to model $\chi_{e,EP}$ in FY14-16 (Crocker, UCLA)

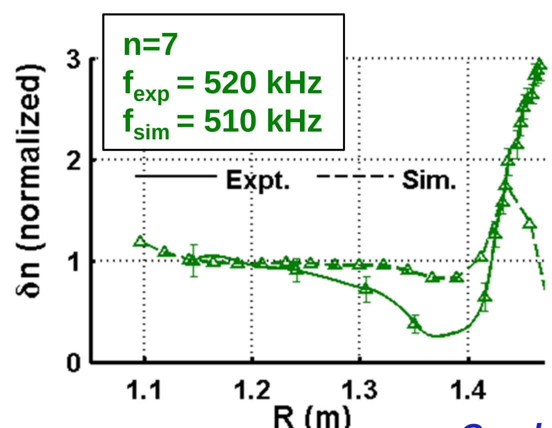
- HYM simulations predict both GAE and CAE
  - E.g, counter propagating GAE frequencies consistent, mode structure shows some discrepancies
  - Measured displacements used to estimate CAE→KAW power channeling, $P_{CAE\rightarrow KAW} \sim \gamma(\delta B)^2$, $\delta B \sim \xi$

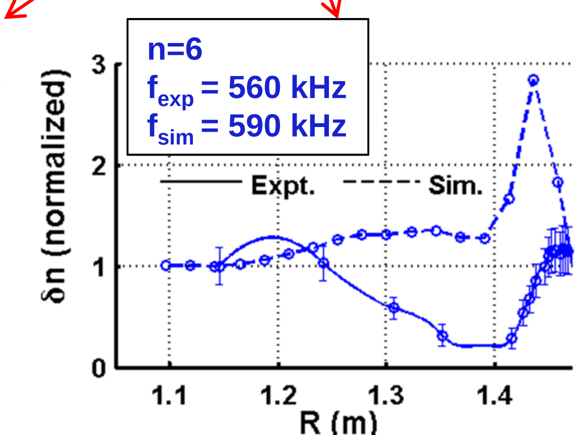
Crocker, NF (2013)



Will test additional physics in HYM simulations in FY14-16
(E. Belova, PPPL Theory)

FY17+ goal of fully nonlinear, self-consistent HYM predictions of $\chi_{e,EP}$ and $P_{CAE\rightarrow KAW}$



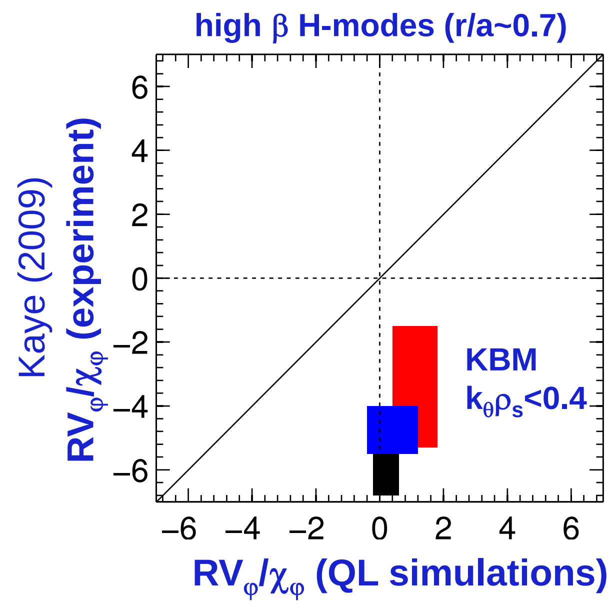


Crocker, IAEA (2014)

Momentum transport predictions being used to help constrain theory

$$\Pi_\varphi = \underbrace{\chi_\varphi u'}_{\#1} + \underbrace{V_\varphi u}_{\#2} + \underbrace{Cuu'}_{\#3} + \underbrace{\chi_{\varphi\perp}\gamma_E}_{\#4} + \underbrace{\Pi_{RS}}_{\#5}$$

- Coriolis pinch (**#2**) for ITG generally describes conventional aspect ratio results
  - Microtearing (MT) & kinetic ballooning modes (KBM) predicted in NSTX H-modes, calculated pinch is inconsistent

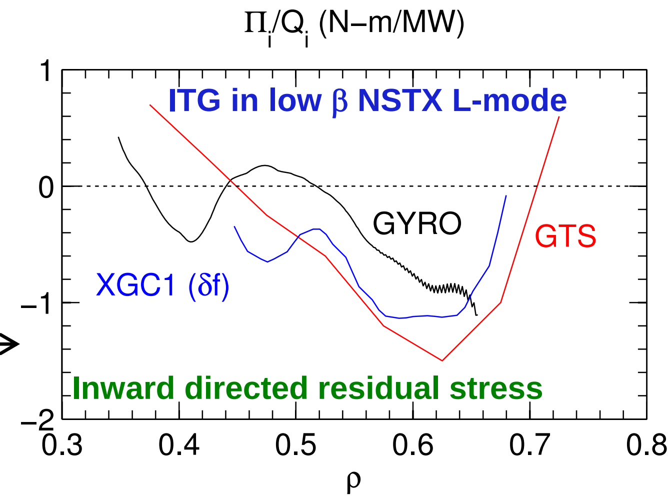


Investigating centrifugal effects (**#3**) in FY14, collaboration with U-Bayreuth, GKW (Buccholz)

- Simulation challenges at high β motivated analysis in low β L-modes
  - Nonlinear simulations with E×B shear (**#4**) predict weak pinch, even for low β ITG
  - Led perturbative L-mode experiments at MAST using 3D δB fields (2013) – analysis ongoing

Collaboration with CCFE

- Investigating finite-ρ_* effects for momentum transport in low-β L-mode
  - Global GTS, GYRO & XGC1 (δf) simulations predict inward directed residual stress (**#5**) in absence of flow ($u=u'=\gamma_E=0$)



Ongoing global benchmark in FY14-15

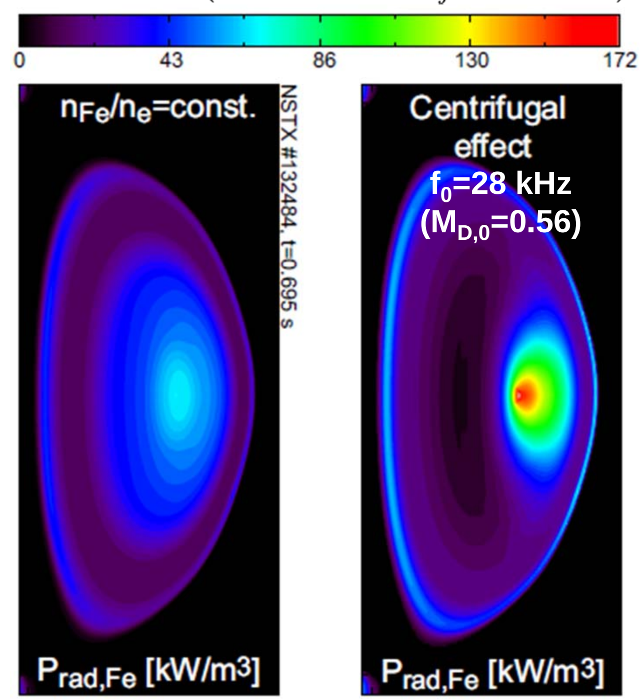
NSTX-U will study low- and high-Z impurity transport prior to significant high-Z PFC coverage in FY17+

- Impurity transport studies will be accomplished using gas-puff (Ne, Ar), laser blow off (Ca, Mo, W – FY16, LLNL/JHU) and many diagnostic enhancements:
  - Survey x-ray spectrometers (LLNL)
  - XCIS: $V_{\varphi,Z}$, T_Z, n_Z (Ca, Ar, Mo, W) (PPPL)
  - 1D tangential mid-plane + 2D poloidal bolometers (PPPL)

Collaboration between LLNL, JHU, PPPL

- Will investigate whether high-Z transport follows neoclassical
  - Including toroidal rotation + centrifugal effects on poloidal asymmetry
  - Using 2nd NBI + NTV to vary rotation

$$n_j = n_{j,0} \exp\left(\frac{\frac{1}{2}m_j\omega^2(R^2 - R_0^2) - eZ_j\Delta\Phi}{k_BT_j}\right)$$



Delgado-Aparicio, HTPD (2014)

- Plan to investigate particle transport using edge neutral measurement (D_α from MSE, BES; D_β camera) + DEGAS2 calculations
  - Assess perturbative capability using TS, ME-SXR
  - Perturbative particle transport measurements led on MAST in 2013 (Ren) – analysis ongoing

Collaboration with CCFE

OUTLINE

- Recent research highlights

- Research goals and plans for FY15-16
  - Thrust 1: Characterize H-mode energy confinement at low ν_*
  - Thrust 2: Identify regime of validity for mechanisms responsible for χ_e, χ_i, χ_φ, D_{imp}
  - Thrust 3: Establish and validate reduced transport models

- Summary

FY15 research plans

Thrust 1

- Characterize H-mode confinement scaling at increased B_T/I_p = 0.8 T/1.6 MA
  - Push to lowest collisionality possible (is $\tau_E \sim 1/\nu_*$ still valid?) **R15-1**
  - Characterize changes in multi-channel transport χ_e, χ_i, χ_φ, D_{imp} (e.g., does $\chi_i \approx \chi_{i,NC}$ & $D_i \approx D_{i,NC}$ remain at lower ν_*)
  - Compare with theory (e.g., is microtearing suppressed at reduced ν_*?)

Thrust 2

- Explore parametric transport and turbulence dependencies with q and flow profiles using expanded NBI flexibility, 3D coils **JRT 15**
  - Characterize changes in low-k turbulence (BES, reflectometry), compare with gyrokinetic simulations
- Measure CAE/GAE mode frequencies and structure (BES, reflectometry)
  - Characterize effect of GAE/CAE on experimental χ_e, sensitivity to NBI tangency radii/pitch angle
  - Compare with theory, HYM simulations

w/ EP
R15-2

Thrust 3

- Develop & test $\chi_{e,EP}$ model using ORBIT + measurement/HYM predictions
  - Test sensitivity of GAE/CAE measurements, predictions to fast ion phase space

FY15-16 research plans

Thrust 2

- Investigate momentum transport using NBI modulation from additional beam sources, longer duration discharges
  - Characterize Pr, RV_φ/χ_φ in low- and high-β discharges, compare with theory
  - Study intrinsic rotation in Ohmic & RF discharges using passive CHERS, MSE-LIF (FY16)
- Measure high-Z impurity transport prior to significant high-Z PFC coverage (FY17+); Assess effect of HHFW
  - Perturbative experiments (D, V) for impurity and electron thermal transport using trace Ne, Ar (puff) and high-Z (LBO), coupled with ME-SXR, XCIS

Thrust 3

- Continue turbulence simulations with increasing realism
  - Finite-ρ_*, toroidal flow effects for high-β electromagnetic turbulence
- Develop, test reduced drift wave transport models (e.g. TGLF)
  - Test fidelity of models with gyrokinetic simulations for broad parameter space
  - Predict T_e, T_i profiles to validate models with experiments

FY16 research plans

Thrust 1

- Extend H-mode confinement scaling up to full B_T/I_p = 1.0 T/2.0 MA, P_{NBI}=15 MW
  - Access lowest collisionality (dual LiTER, ELM pacing; cryo after FY17)
  - Characterize changes with addition of high-Z divertor tiles

Thrust 2

- Obtain first data from new turbulence diagnostics
  - High-k FIR scattering: investigate ETG turbulence, k_θ-k_r isotropy; probe high field side δn for evidence of KAW resonance
  - 288 GHz polarimeter: investigate magnetic fluctuations associated with microtearing, GAE/CAE
- Assess confinement, local transport and turbulence at low ν_* with full confinement and diagnostic capabilities (resources permitting) ***IR16-1***
  - Comprehensive low-k, high-k, and magnetic turbulence coverage (BES, high-k, polarimeter, reflectometer), compare with simulations & reduced models
  - Study in isolated regimes of microinstabilities (MT vs. ETG vs. ITG/TEM/KBM)

Summary: NSTX-U T&T research in FY15-16 will advance physics basis for predictive capability

- Characterize confinement scaling for high beta, lowest collisionality plasmas
  - Evaluate 0D performance for ST-FNSF designs

- Analyze multi-channel transport (χ_i, χ_e, χ_φ, V_φ, D_{imp}, V_{imp}), turbulence measurements (low-k, high-k, magnetic), effects of GAE/CAE-KAW to discriminate most important transport mechanisms
  - Motivate new theory, models and/or diagnostics (PCI, DBS, CPS)

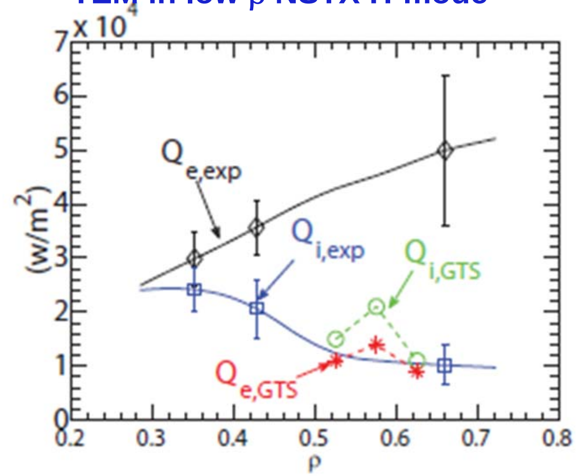
- Continue assessment of predictive capability of reduced transport models $\rightarrow$ improve prediction of confinement (τ_E) and temperature (T_e, T_i) profiles

BACKUP SLIDES

Global simulations used increasingly to investigate electrostatic ion scale turbulence

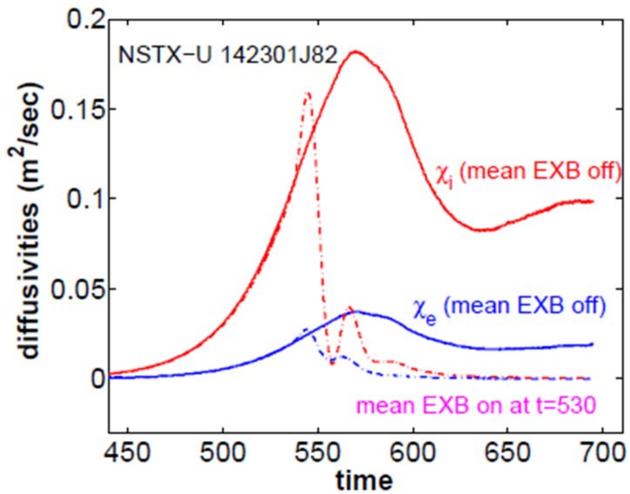
- Investigating TEM turbulence in low-β NSTX H-mode where ETG has been reduced by large ∇n (Ren, PRL 2011, PoP 2012)
  - TEM predicts substantial ion and momentum flux, electron flux below experiment
  - Suggests need for multiscale TEM-ETG simulations

TEM in low β NSTX H-mode



W. Wang – GTS code (PPPL Theory)

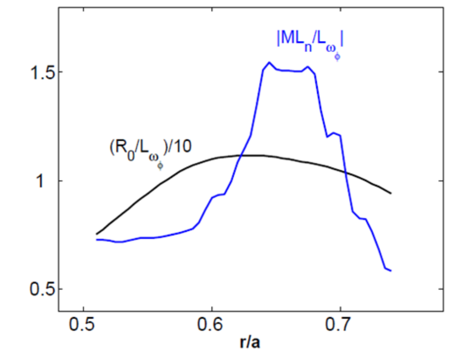
- Global electrostatic GTS sims with kinetic electrons for NSTX-U scenario predict little transport, even without E$\times$B shear
  - Suggests ion transport may remain neoclassical in NSTX-U



Implementing EM effects in GTS in FY14-15 (Startsev, Wang – PPPL Theory)

Strong flow shear can destabilize Kelvin-Helmholtz (K-H) instability in NSTX (Wang, TTF 2014)

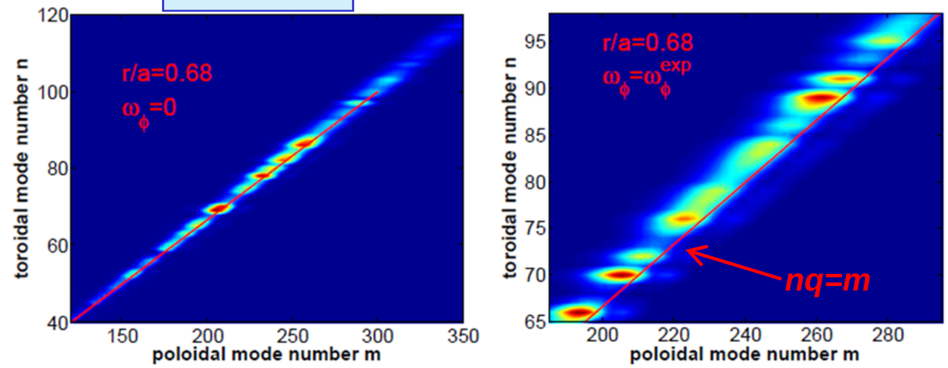
- K-H instability expected for $|ML_n/L_\omega|>1$ from linear analytic theory (Catto, 1973; Garbet, 1999)



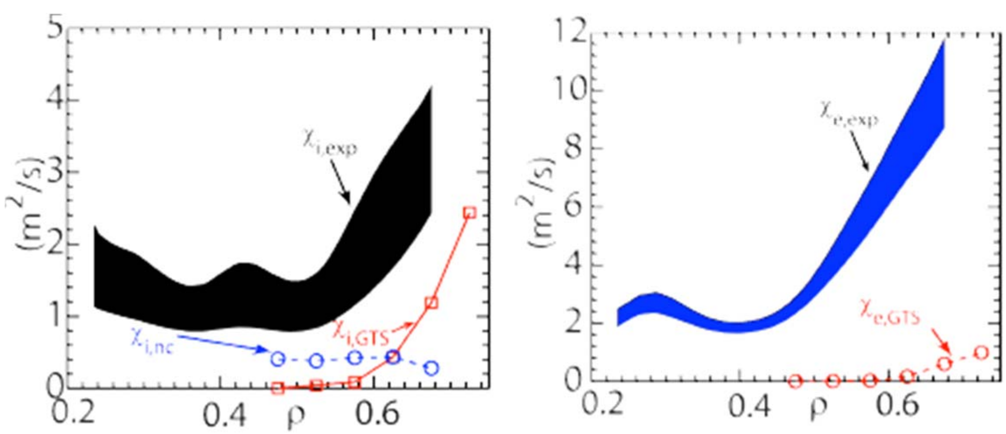
- K-H identified in global electrostatic ITG simulations for NSTX low β L-mode (Ren, 2013)
  - Mostly unstable K-H modes have finite $k_{||}$ (shifted away from nq=m)

$$k_{||} \sim \frac{k_\theta \rho_s}{2c_s}\frac{1}{n}\frac{d(nV_{||})}{dr} \sim \frac{d\omega_\phi}{dr}$$

GTS code



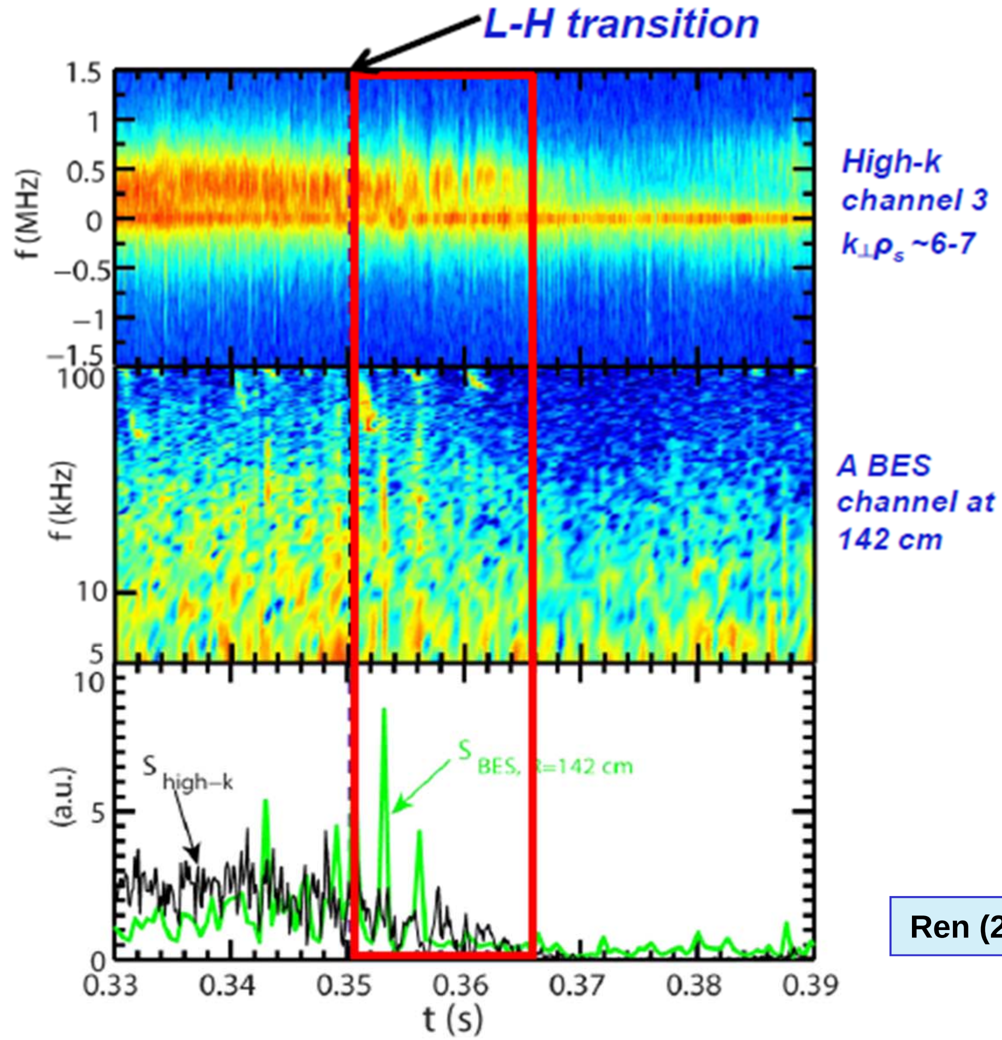
- K-H/ITG + neoclassical close to experiment χ_i
  - χ_e underpredicted
  - ETG possibly important



Nonlinear ETG simulations to be run in FY14 to investigate contribution in NSTX L-modes

Across L-H transition, low-k turbulence measured by BES shows similar temporal behavior as high-k turbulence

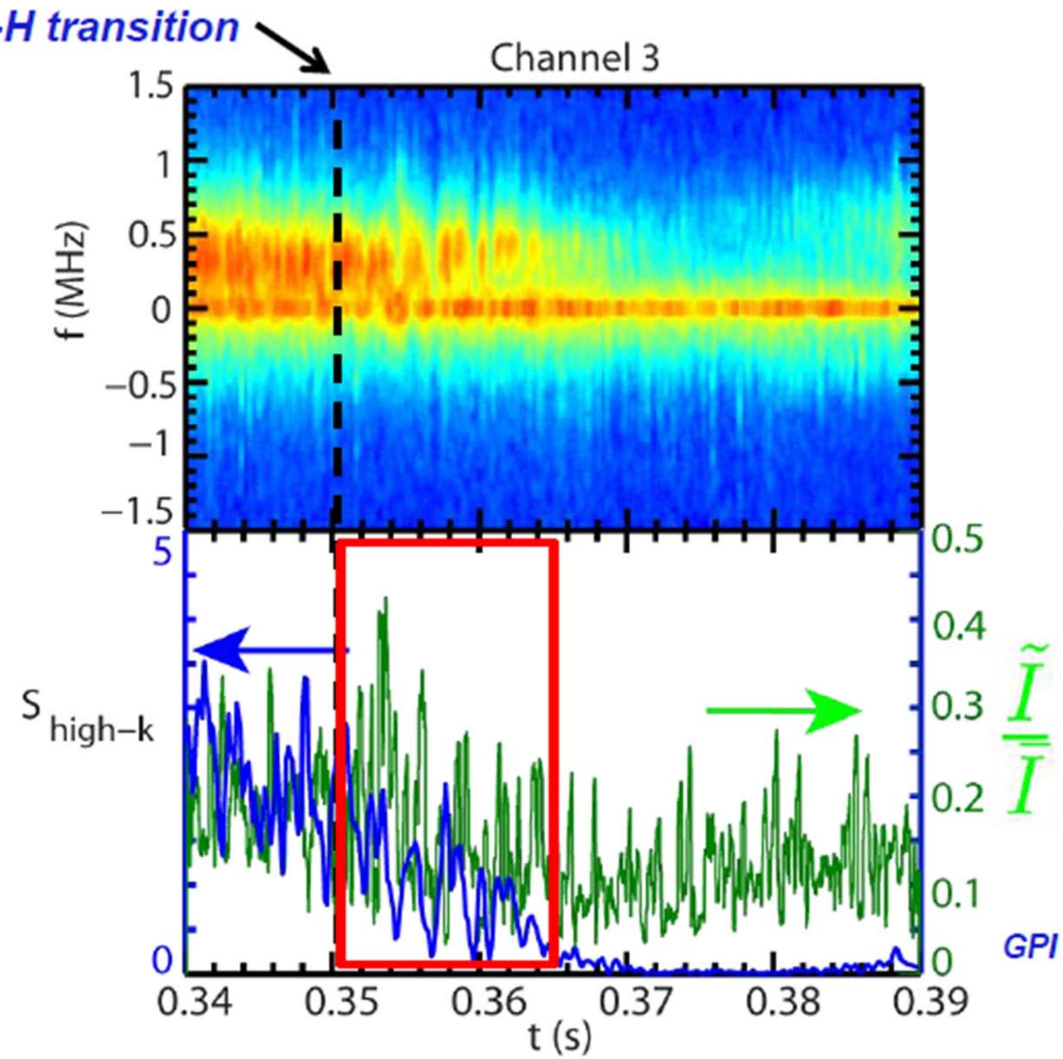
- High-k channel 3 measuring $k_{\perp}\rho_s$ ~6-7 is compared with BES measurement at R=142 cm (top of the H-mode pedestal)



Ren (2014)

- Quasi-stationary turbulence before the L-H transition
  - $\frac{\tilde{n}}{n} \approx 2.9\%$ from BES
- Reduced turbulence into H-mode
  - $\frac{\tilde{n}}{n} \approx 0.94\%$ from BES
- Intermittent turbulence right after the L-H transition
  - t ~ 350-365 ms
  - Similar temporal intermittency in low-k and high-k

Across L-H transition, GPI measurements are more intermittent than high-k turbulence



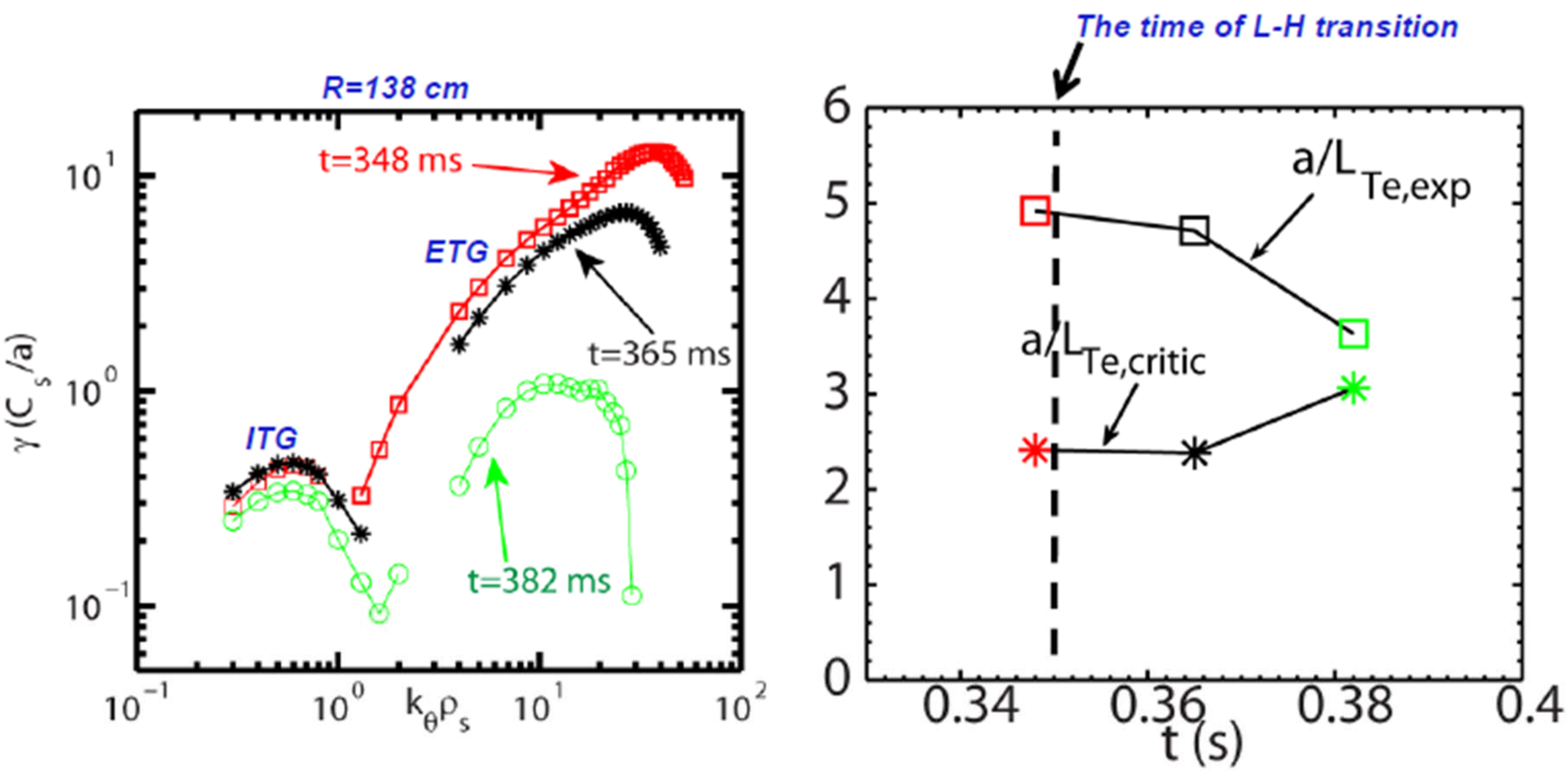
Ren (2014)

- $\tilde{I}$ is the RMS value of the GPI emission fluctuation over every 0.13 ms
- $\bar{I}$ is the mean of the GPI emission over every 0.13 ms

GPI emission at R=144 cm

Electron temperature gradient moves closer to ETG threshold after L-H transition

- The decrease in ETG linear growth rates is due to the decrease of ETG and increase of critical ETG

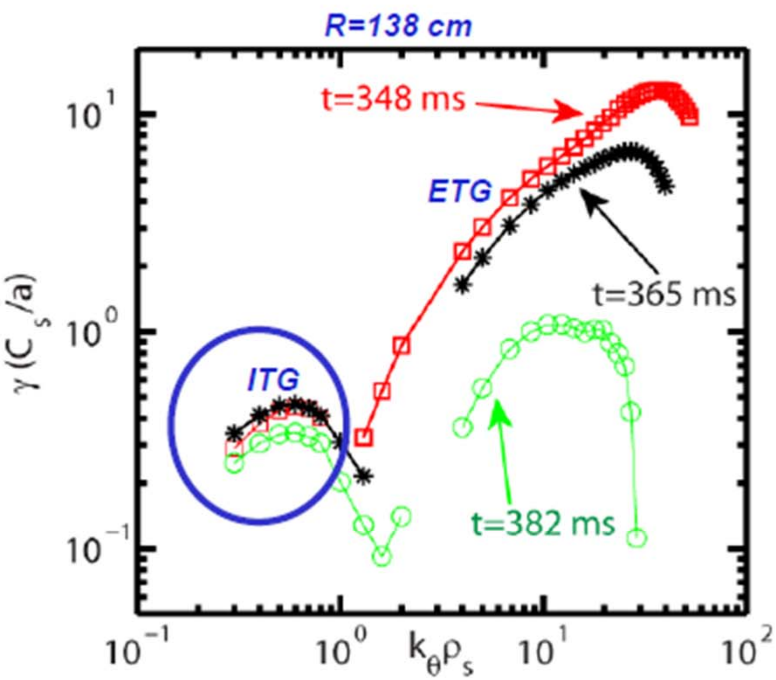


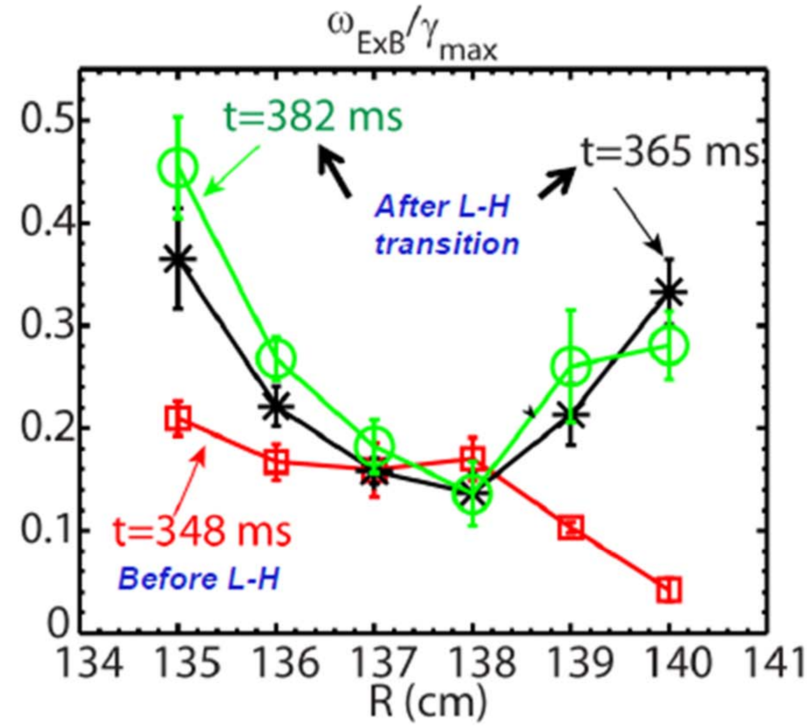
Ren (2014)

- Stability Analysis was performed with the GS2 code (Kotschenreuther et al., 1995) with Miller local equilibrium

Low-k modes expected to be more suppressed after L-H transition

- $\omega_{E\times B,WM}/\gamma_{max}$ increases in the high-k measurement region into H-mode





Ren (2014)

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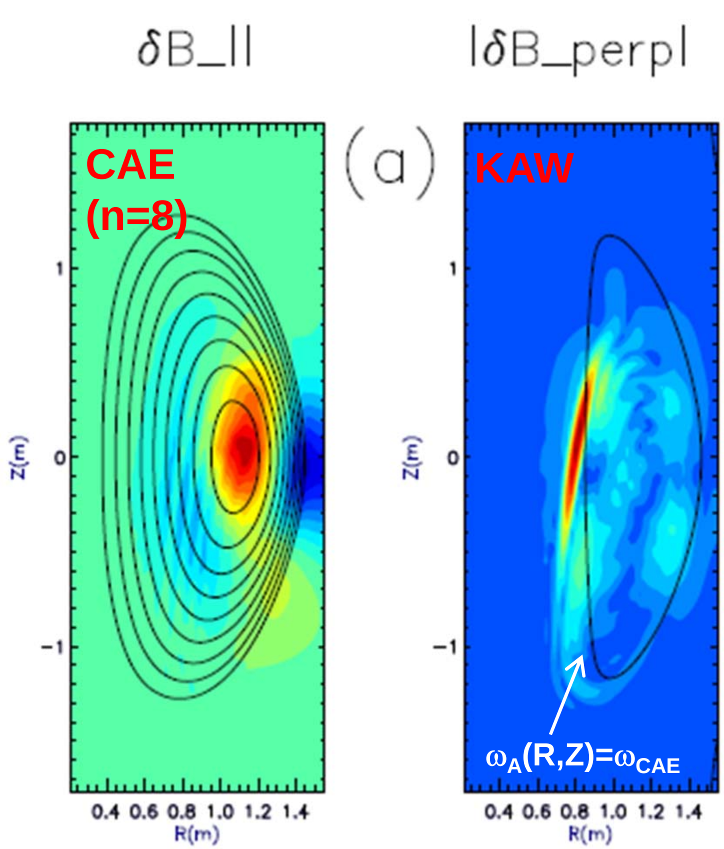
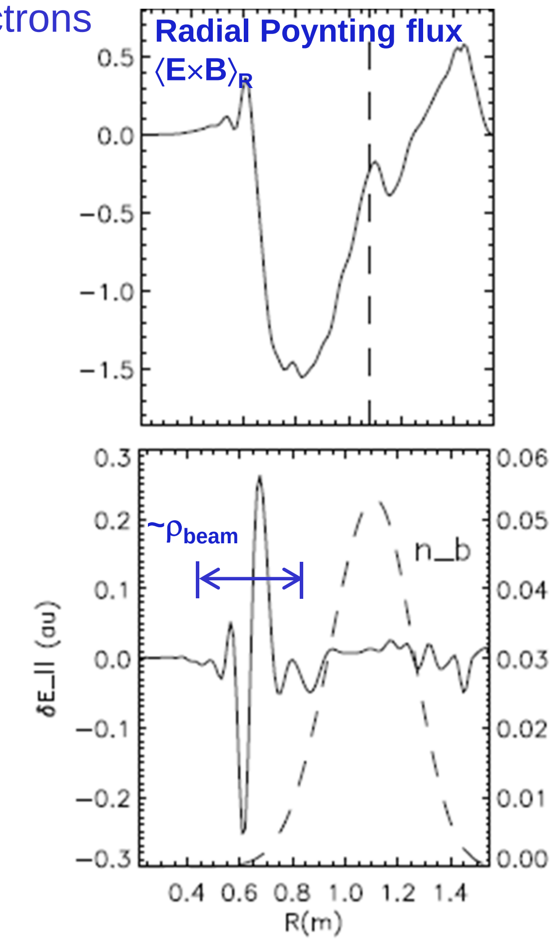
Investigating coupling of CAEs to kinetic Alfvén waves (KAW) as additional energy “loss” mechanism

1) GAE/CAEs cause large χ_e through stochastic orbits [Gorelenkov, NF 2010]
2) CAEs also couple to KAW - Poynting flux redistributes fast ion energy near mid-radius, $E_{||}$ resistively dissipates energy to thermal electrons
   - $P_{CAE\rightarrow KAW}$~**0.4 MW** from QL estimate + experimental mode amplitudes (Belova,IAEA 2014)
   - $P_{e,NBI}$~**1.7 MW** for ρ<0.3, NBI power deposited on core electrons

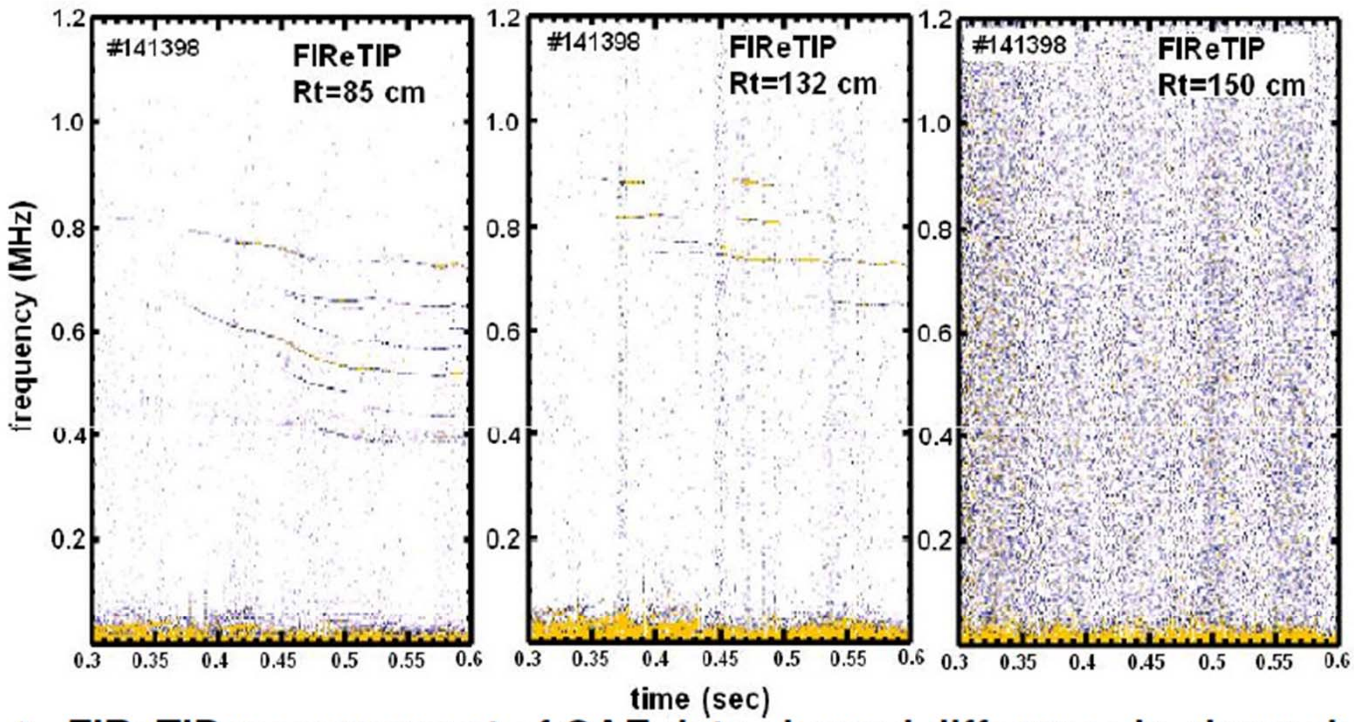
E. Belova – HYM code (PPPL Theory)





Will assess ability of available measurements (FIReTIP, high-k scattering, polarimeter) to measure KAW

Energetic Particle Modes study by FIReTIP on NSTX-U



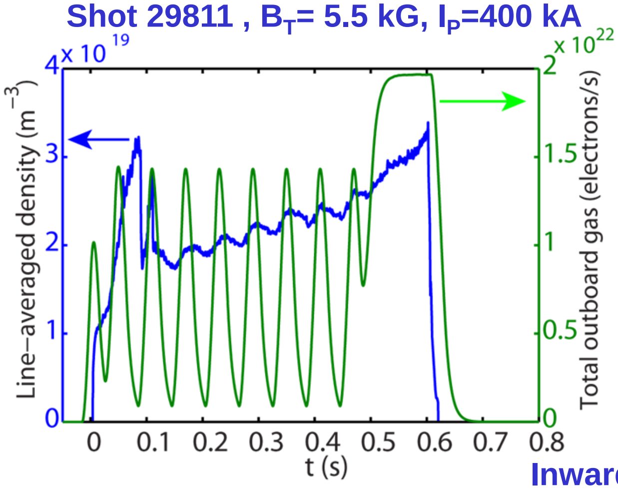
► FIReTIP measurement of GAE data showed difference in channels

► Alfven mode frequency will be doubled on NSTX-U and FIReTIP bandwidth (4 MHz) will cover GAE, CAE, TAE, Angel Fish etc.

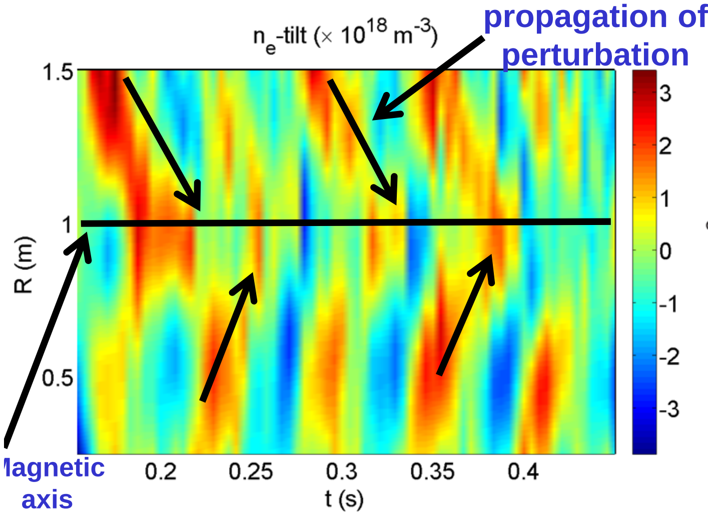
K.C. Lee, APS (2010)

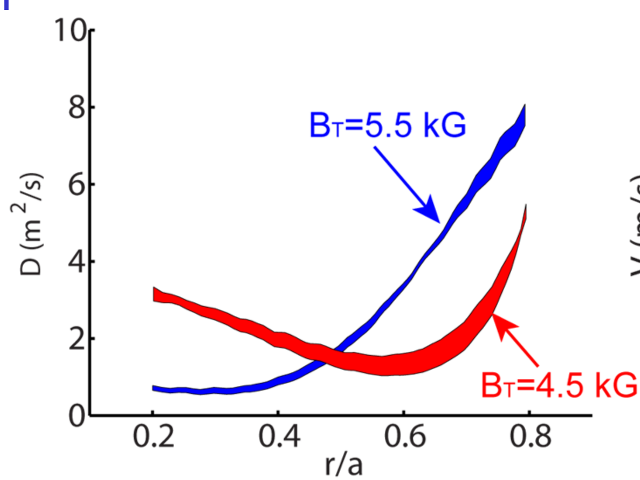
Perturbative Particle Transport Experiment was Carried out on MAST L-mode Plasmas

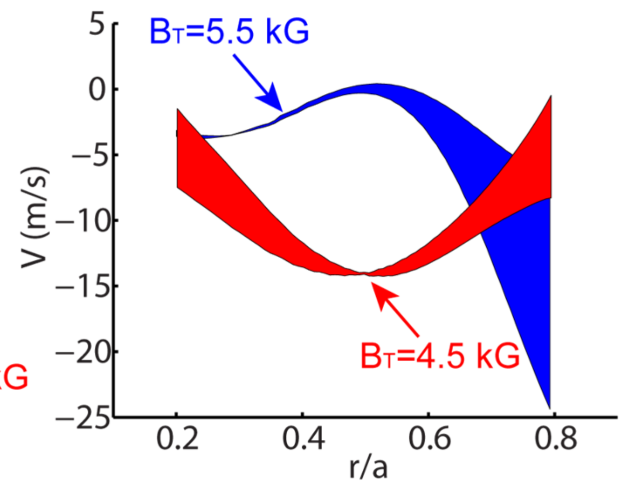
- Modulated gas puff is used to introduce density perturbation
  - Clear density modulation seen in line-averaged density
  - Experiment carried out with different density, current and toroidal field



- Clear inward propagation of density perturbation
- Particle diffusivity, D, and pinch, V, evaluated with Fourier analysis
  - D and V change as toroidal magnetic field is varied

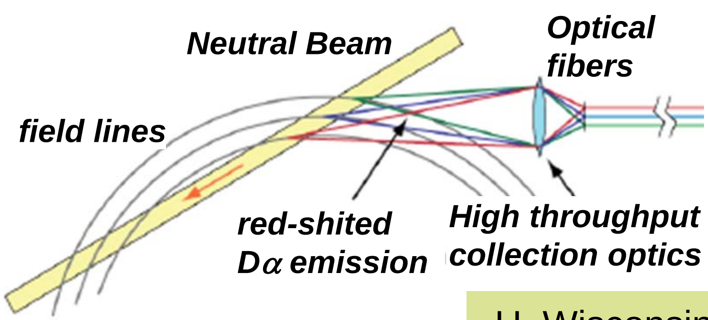






Additional new and upgraded diagnostics critical for T&T research

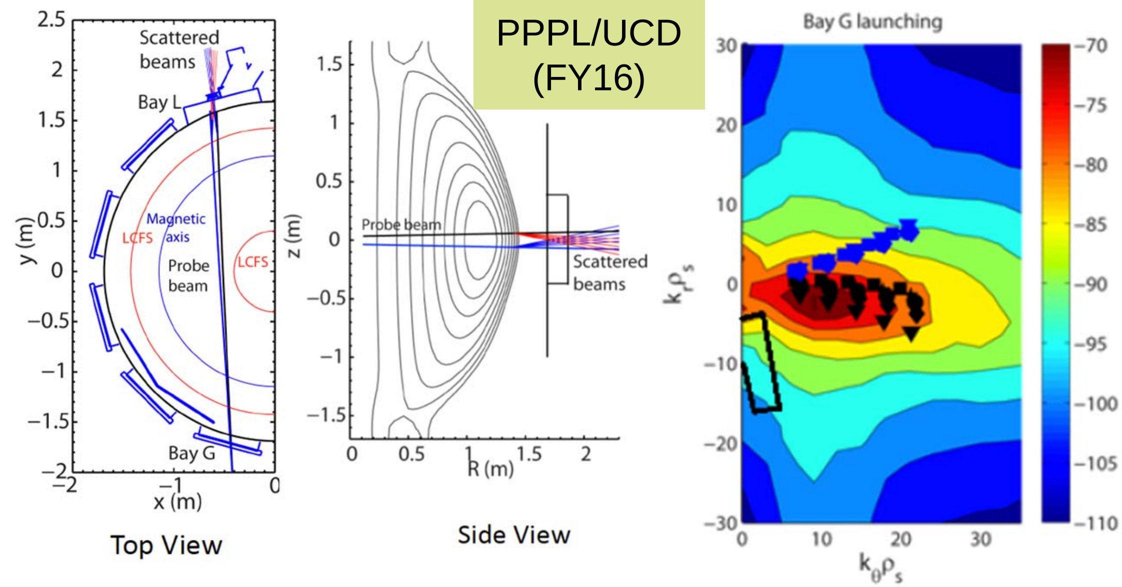
48 ch. BES



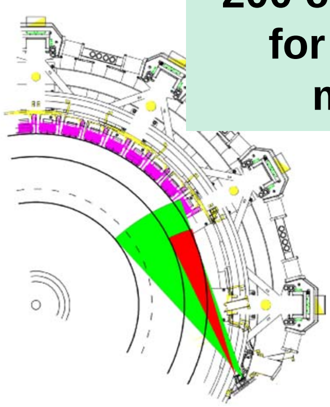
U. Wisconsin (FY15)

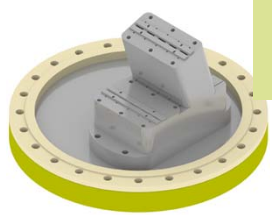
New high-k scattering system for 2-D k spectrum

PPPL/UCD (FY16)



200 ch., 10 kHz ME-SXR for fast T_e, impurity measurements

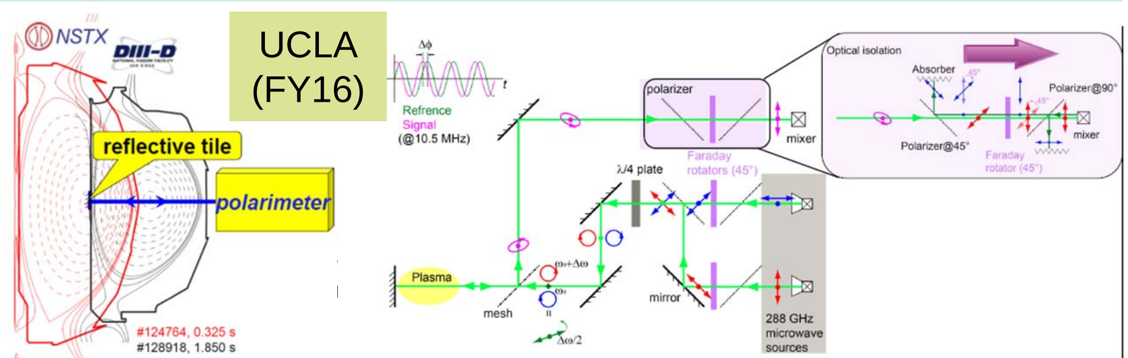




JHU (FY15)

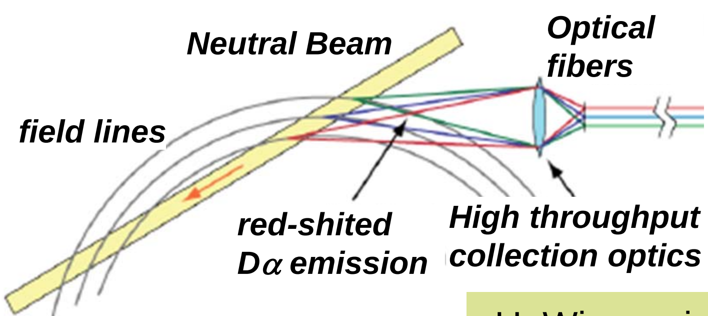
288 GHz polarimetry system for internal magnetic fluctuation measurements (tested on DIII-D in 2012)

UCLA (FY16)



Additional new and upgraded diagnostics critical for T&T research

48 ch. BES



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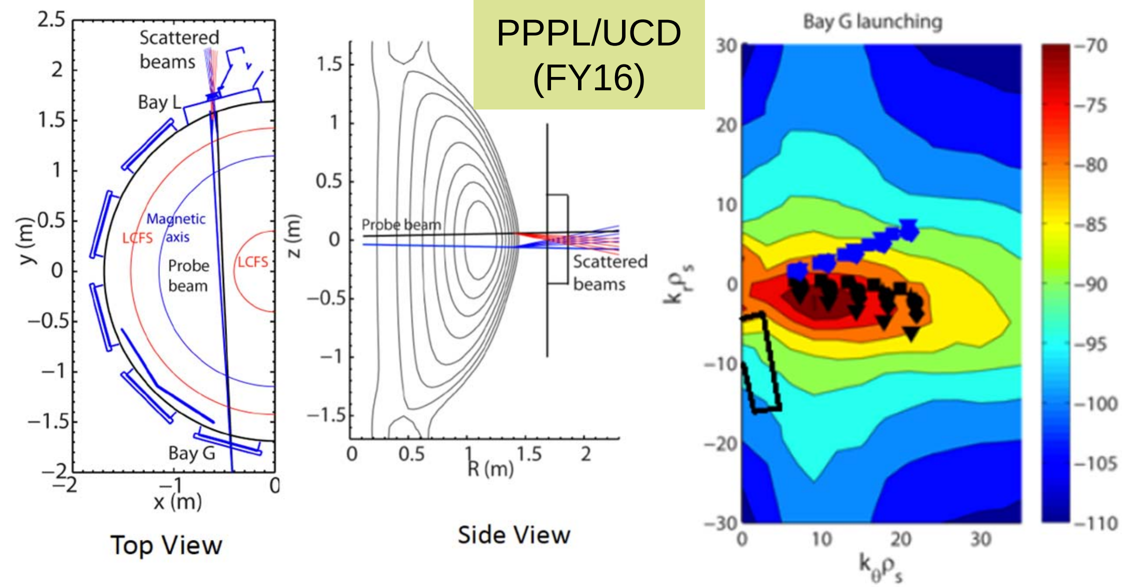


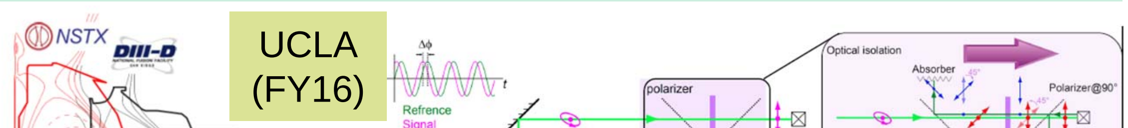
200 ch., 10 kHz ME-SXR for fast T_e, impurity measurements

JHU

Similar system installed & successfully tested on EAST for FY14 operation (prior to NSTX-U operations)

288 GHz polarimetry system for internal magnetic fluctuation measurements (tested on DIII-D in 2012)

UCLA (FY16)

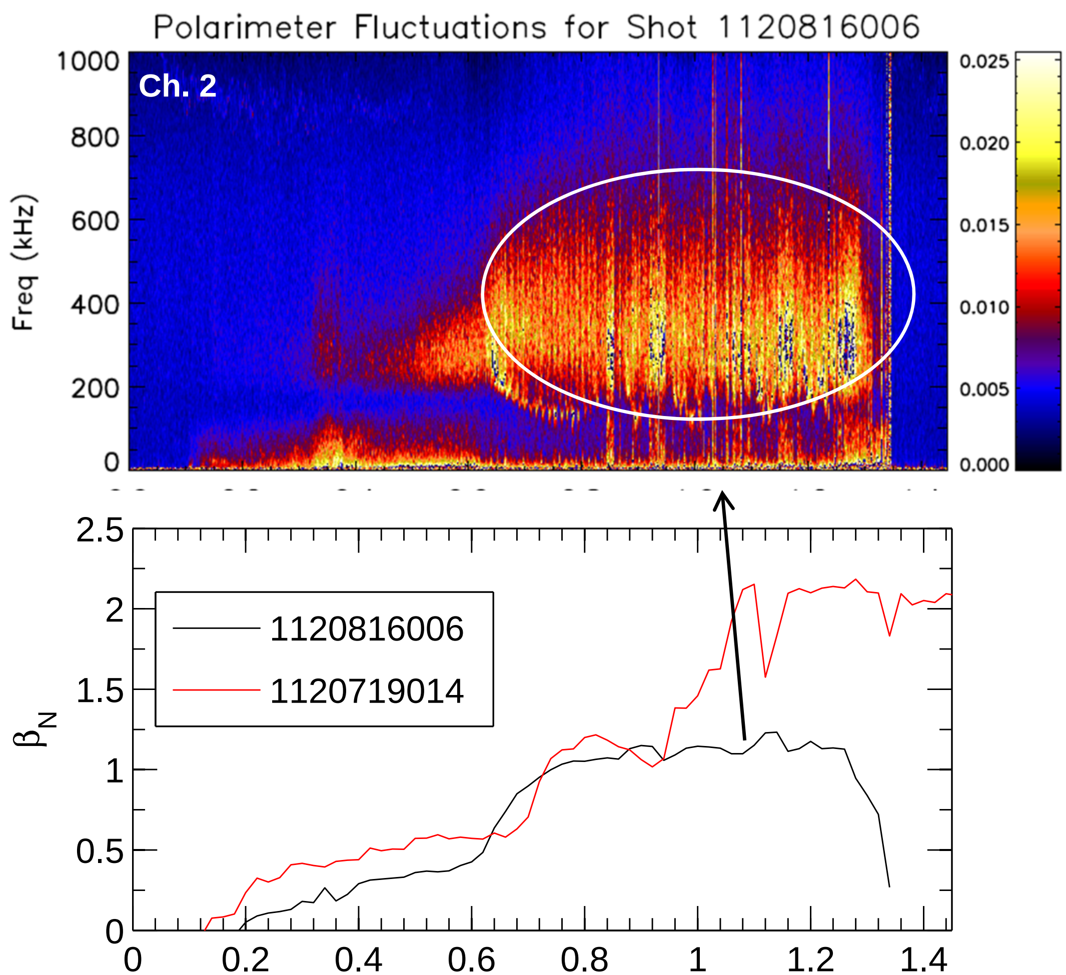


Ongoing FY14 collaboration with C-Mod and DIII-D to investigate electromagnetic effects and interpretation of line-integrated polarimetry (C-Mod) and cross-polarization scattering (DIII-D) measurements

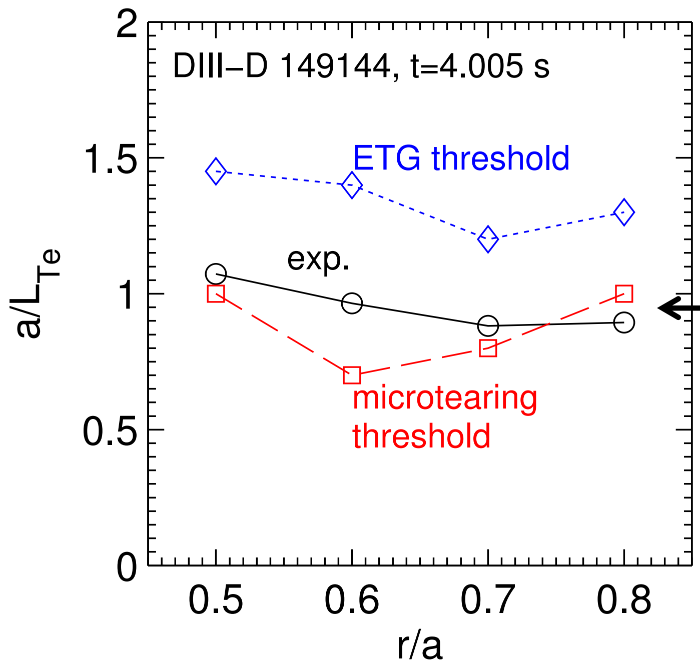
Collaborating with C-Mod to investigate electromagnetic effects & diagnostics related to NSTX-U

- Broadband fluctuations observed in C-Mod line-integrated polarimeter (~$n_e \cdot B$), not seen in PCI (~n_e only) (Bergerson, RSI 2012)

- Collaborating on gyrokinetic analysis and measurement interpretation in anticipation of related NSTX-U research
  – Experimental run time allocated for FY14 to investigate β_N~2 ITER-like scenarios, hopefully with new polarimeter data

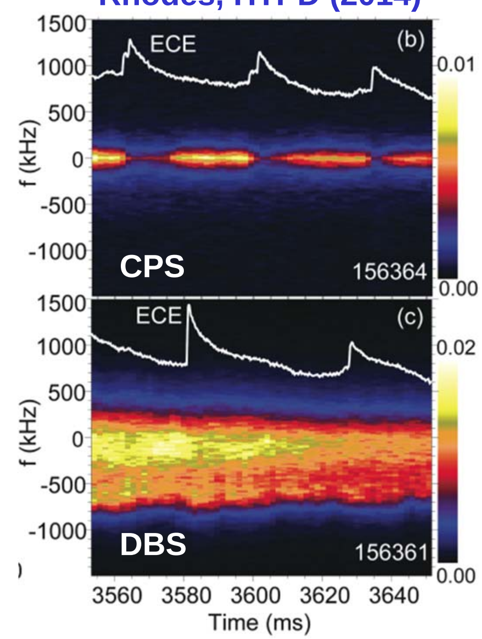


Collaborating with DIII-D to investigate electromagnetic effects & diagnostics related to NSTX-U



- Ion thermal & momentum transport found to be neoclassical in DIII-D high density QH-mode (Holland, TTF 2013) – similar to NSTX H-modes
  - Gradients nearest to microtearing threshold

Rhodes, HTPD (2014)



- UCLA implementing cross-polarization scattering (CPS) to measure internal magnetic fluctuations
  - Collaborating on gyrokinetic analysis and interpretation to evaluate possible implementation and utility on NSTX-U

A Summary of Acronyms (SoA)

- Instabilities
  - ITG – ion temperature gradient, electrostatic
  - TEM – trapped electron mode, electrostatic
  - KBM – kinetic ballooning mode, electromagnetic
  - MT – microtearing, electromagnetic
  - ETG – electron temperature gradient, electrostatic
  - CAE – compressional Alfven eigenmode, electromagnetic
  - GAE – global Alfven eigenmode, electromagnetic
- Codes
  - GYRO – an eulerian gyrokinetic code
  - GS2 – an eulerian gyrokinetic code
  - GTS – global particle-in-cell Gyrokinetic Tokamak Simulation (GTS) code
  - GENE – Gyrokinetic Electromagnetic Numerical Experiment (GENE) code
  - XGC0/XGC1 –full-f global particle-in-cell gyrokinetic code
  - TGLF – an gyro-Landau-fluid code
  - MMM08 – multi-mode anomalous transport model
  - NCLASS – a local neoclassical transport code
  - NEO – a local eulerian neoclassical transport code
  - GTC-NEO –a global particle-in-cell neoclassical transport code
  - HYM – nonlinear 3-D HYbrid and MHD simulation code (HYM)
  - TRANSP – a time dependent tokamak transport and data analysis code with free boundary and multi-zone predictive capability
  - TGYRO – a transport solver
  - MIST – Multi-Ionic Species Transport (MIST) code
  - STRAHL – an impurity transport code
  - DEGAS2– a neutral transport code
  - ORBIT – A guiding center test particle code for tokamak geometry
- Diagnostics
  - BES – beam emission spectroscopy (BES)
  - CHERS – charge exchange recombination spectroscopy (CHERS)
  - ME-SXR – multi-energy soft X-ray (ME-SXR)
  - TGIS – Transmission Grating Imaging Spectrometer (TGIS)
  - LBO – Laser Blow-off system (LBO)

Joint Research Target 2015

FY2015 Office of Fusion Energy Sciences 3 Facility Joint Research Milestone:

Responsible TSGs: Energetic Particles, Advanced Scenarios, Macroscopic Stability, T&T

Conduct experiments and analysis to quantify the impact of broadened current and pressure profiles on tokamak plasma confinement and stability. Broadened pressure profiles generally improve global stability but can also affect transport and confinement, while broadened current profiles can have both beneficial and adverse impacts on confinement and stability. This research will examine a variety of heating and current drive techniques in order to validate theoretical models of both the actuator performance and the transport and global stability response to varied heating and current drive deposition.

Milestone R(15-1)

R(15-1): Assess H-mode energy confinement, pedestal, and scrape off layer characteristics with higher B_T, I_P and NBI heating power

Responsible TSGs: Transport and Turbulence, Boundary Physics, Advanced Scenarios

Future ST devices such as ST-FNSF will operate at higher toroidal field, plasma current and heating power than NSTX. To establish the physics basis for future STs, which are generally expected to operate in lower collisionality regimes, it is important to characterize confinement, pedestal and scrape off layer trends over an expanded range of engineering parameters. H-mode studies in NSTX have shown that the global energy confinement exhibits a more favorable scaling with collisionality ($B\tau_E \sim 1/\nu^*_e$) than that from ITER98y,2. This strong ν^*_e scaling unifies disparate engineering scalings with boronization ($\tau_E{\sim}I_p^{0.4}B_T^{1.0}$) and lithiumization ($\tau_E \sim I_P^{0.8}B_T^{-0.15}$). In addition, the H-mode pedestal pressure increases with $\sim I_P^2$, while the divertor heat flux footprint width decreases faster than linearly with I_P. With double B_T, double I_P and double NBI power with beams at different tangency radii, NSTX-U provides an excellent opportunity to assess the core and boundary characteristics in regimes more relevant to future STs and to explore the accessibility to lower collisionality. Specifically, the relation between H-mode energy confinement and pedestal structure with increasing I_P, B_T and P_{NBI} will be determined and compared with previous NSTX results, including emphasis on the collisionality dependence of confinement and beta dependence of pedestal width. Coupled with low-k turbulence diagnostics and gyrokinetic simulations, the experiments will provide further evidence for the mechanisms underlying the observed confinement scaling and pedestal structure. The scaling of the divertor heat flux profile with higher I_P and P_{NBI} will also be measured to characterize the peak heat fluxes and scrape off layer widths, and this will provide the basis for eventual testing of heat flux mitigation techniques. Scrape-off layer density and temperature profile data will also be obtained for several divertor configurations, flux expansion values, and strike-point locations to validate the assumptions used in the FY2012-13 physics design of the cryopump to inform the cryo-pump engineering design to be carried out during FY2015.

Mileston R(15-2)

R(15-2): Assess the effects of neutral beam injection parameters on the fast ion distribution function and neutral beam driven current profile

Responsible TSGs: Energetic Particles, Transport and Turbulence

Accurate knowledge of neutral beam (NB) ion properties is of paramount importance for many areas of tokamak physics. NB ions modify the power balance, provide torque to drive plasma rotation and affect the behavior of MHD instabilities. Moreover, they determine the non-inductive NB driven current, which is crucial for future devices such as ITER, FNSF and STs with no central solenoid. On NSTX-U, three more tangentially-aimed NB sources have been added to the existing, more perpendicular ones. With this addition, NSTX-U is uniquely equipped to characterize a broad parameter space of fast ion distribution, F_{nb}, and NB-driven current properties, with significant overlap with conventional aspect ratio tokamaks. The two main goals of the proposed Research Milestone on NSTX-U are (i) to characterize the NB ion behavior and compare it with classical predictions, and (ii) to document the operating space of NB-driven current profile. F_{nb} will be characterized through the upgraded set of NSTX-U fast ion diagnostics (e.g. fast-ion D-alpha: FIDA, solid-state neutral particle analyzer: ssNPA, scintillator-based fast-lost-ion probe: sFLIP, and neutron counters) as a function of NB injection parameters (tangency radius, beam voltage) and magnetic field. Well controlled, single-source scenarios at low NB power will be initially used to compare fast ion behavior with classical models (e.g. the NUBEAM module of TRANSP) in the absence of fast ion driven instabilities. Diagnostics data will be interpreted through the "beam blip" analysis technique and other dedicated codes such as FIDASIM. Then, the NB-driven current profile will be documented for the attainable NB parameter space by comparing NUBEAM/TRANSP predictions to measurements from Motional Stark Effect, complemented by the vertical/tangential FIDA systems and ssNPA to assess modifications of the classically expected F_{nb}. As operational experience builds up during the first year of NSTX-U experiments, additions to the initial F_{nb} assessment will be considered for scenarios where deviations of F_{nb} from classical predictions can be expected. The latter may include scenarios with MHD instabilities, externally imposed non-axisymmetric 3D fields, and additional High-Harmonic Fast Wave (HHFW) heating.

Milestone IR(16-1)

IR(16-1): Assess τ_E and local transport and turbulence at low ν^* with full confinement and diagnostic capabilities

Future ST devices such as ST-FNSF will operate at higher toroidal field, plasma current and heating power than NSTX. To establish the physics basis for future STs, which are generally expected to operate in lower collisionality regime, it is important to characterize confinement trends over an expanded range of engineering parameters. H-mode studies in NSTX have shown that the global energy confinement exhibits a more favorable scaling with collisionality ($B\tau_E \sim 1/\nu^*_e$) than that from ITER98y,2. This strong ν^*_e scaling unifies disparate engineering scalings with boronization ($\tau_E \sim I_P^{0.4} B_T^{1.0}$) and lithiumization ($\tau_E \sim I_P^{0.8} B_T^{-0.15}$). Milestone R15-1 will provide initial data on how increasing plasma current, toroidal field and heating power will affect global energy confinement and access to lower collisionality in NSTX-U (compared to NSTX). During FY16 it will become feasible to assess confinement and local transport dependences over the widest range of accessible B_T (1T), I_P (2 MA), and P_{NBI} (15 MW). The addition of the upward facing LiTER will allow Lithium coating on the upper divertor, providing enhanced wall pumping and presumably allowing the greatest flexibility to access minimum ν^*. During this run time it is expected that the new high-k microwave scattering and polarimetry diagnostics will become operational (resources permitting), allowing acquisition of critical new turbulence data while operating over an extended range of parameter space. The new high-k scattering system will allow for an initial assessment of possible turbulence anisotropy and the polarimeter will provide initial data to assess the importance of magnetic microturbulence on confinement and transport. Coupled with gyrokinetic simulations and existing low-k turbulence measurements, these additional datasets will help distinguish between various theoretical transport mechanisms underlying the confinement scaling trends (e.g. micro-tearing vs. ETG).